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Q DISEASE ON 350-MHZ SPOKE CAVITIES*

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Abstract

Q disease, i.e., an increase of RF surface resistance due to hydride precipitation, has been investigated with 350-MHz spoke cavities. This phenomenon was studied extensively in the early 1990s with cavities at frequencies >1 GHz. This is possibly due to the fact that the lower-frequency cavities were believed to show insignificant effect. However, early 500-MHz KEK elliptical cavities and JAERI 130-MHz quarter wave resonators have shown significant Q degradation, suggesting that this disease can be a serious problem with lower-frequency cavities as well. Since there were no quantitative data with 350-MHz cavities, we decided to measure our two spoke cavities. Our spoke cavities were made of RRR~250 niobium and were chemically polished ~150 microns. A few series of systematic tests have shown that our spoke cavities do not show any Q_0 degradation after up to ~24 hours of holding the cavity at 100 K. However, it starts showing degradation if it is held for a longer time and the additional loss due to the Q disease increases linearly. It was also found that our spoke cavity recovers from Q disease if it is warmed up to 150 K or higher for 12 hours.

INTRODUCTION

Q disease would pose a serious problem in the system where superconducting (SC) cavities cannot be cooled down in a short time. Although degassing hydrogen at >600 °C and careful surface treatment can cure this problem, heat treatment costs a significant amount of money and the niobium (Nb) softens. Thus, understanding the mechanism of Q disease and developing a way of treating the SC cavities without heat treatment will be beneficial. We have been investigating the Q disease using our 350-MHz spoke cavities named EZ01 and EZ02 [1, 2].

The first systematic test of checking the holding temperature range in which Q disease occurs suggested that the Q disease might occur after some time even if it does not occur during the first 12 hours [2]. This paper presents recent findings on the Q disease of the LANL 350-MHz spoke cavities.

TEST PROCEDURE

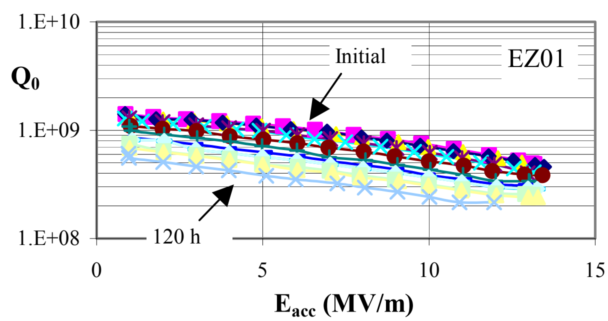
We took the Q_0-E_{acc} curves after warming up the cavity from 4 K to an intermediate temperature (70 – 150 K), holding it there for 12 hours and cooling it down to 4 K again. The detailed time evolution of the temperature during the test can be found elsewhere [1, 2]. When we tested the dependence on the holding time at 100 K, we repeated this procedure and used an accumulated time as the holding time, assuming the effect is the same as that of holding the cavity at 100 K continuously.

RESULTS

Since we found that the Q disease occurs in our spoke cavities [1, 2], we started checking the temperature range of this occurrence by holding the cavity at temperatures starting from 70 K through 150 K every 10 K for 12 hours. However, it was found after a series of tests that the Q disease does not occur within 24 hours at any temperature for our spoke cavities. We then started to test more prolonged holding times at 100 K, expecting from the past tests with longer holding times that the Q disease should occur

Holding time dependence

Figure 1 shows a collection of Q_0-E_{acc} curves after every 12 hours of holding at 100 K up to 120 hours for our two spoke cavities EZ01 and EZ02. These two cavities were fabricated from the same Nb sheets of RRR~250.



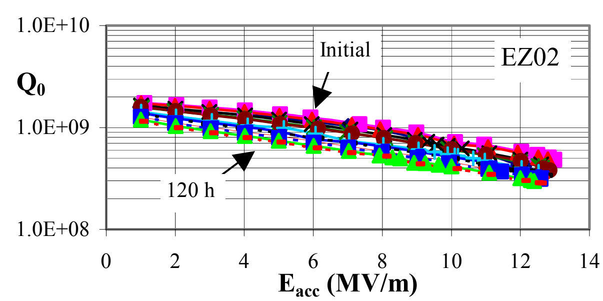


Figure 1: A collection of Q_0-E_{acc} curves of the cavities EZ01 (top) and EZ02 (bottom) measured at 4 K after every 12 hours of holding the cavity at 100 K up to 120 hours.

As one can see, the Q disease occurred on both cavities, but the amount of degradation was different.

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Figure 2 shows the additional surface resistance as a function of the accumulated holding time with 0 being the initial value. It was found that the additional surface resistance starts increasing at ~24 hours and it increases linearly. This linear increase is consistent with published data [3].

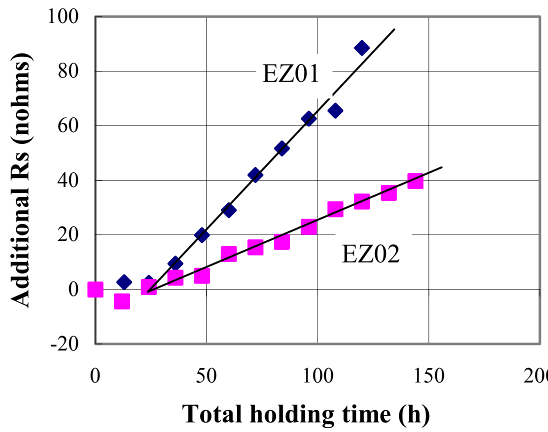

Figure 2: Additional surface resistance due to Q disease as a function of accumulated holding time at 100 K. The data was taken at E_{acc}=4 MV/m.

Surface resistance vs. temperature

Figure 3 shows the surface resistance R_s of the initial cavity (top) and the Q-degraded cavity (bottom). It was found that there is a kink at ~2.18 K in the Q-degraded cavity, below which the R_s gets lower more rapidly. This suggests the existence of a weak superconductor that has a T_c of ~2.18 K.

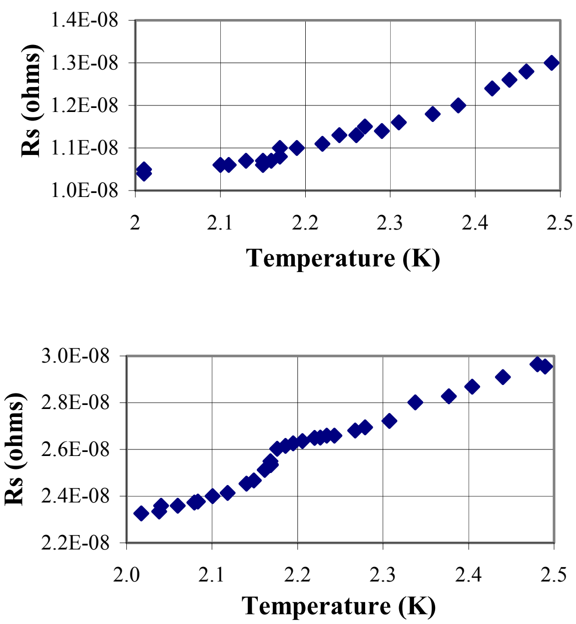

Figure 3: Surface resistance R_s as a function of temperature of the initial (top) and Q-degraded cavity EZ02 (bottom).

Very low field behavior

We checked the Q_0 at field levels lower than E_{acc}=1 MV/m that corresponds to a peak magnetic field B_{peak}=7.38 mT. Figure 4 shows a Q_0-E_{acc} curve at 2 K, including those data, with the cavity EZ02 that was held at 100 K for a total of 180 hours. It was found that the slope of the curve is steeper at these field levels, and the Q_0 increases as the field gets lower. This steep Q_0 drop at E_{acc}<1 MV/m means a rapid increase of RF losses at these low field levels, i.e., there exists some mechanism that causes it such as a superconductor that has a low critical magnetic field or an increase of so-called weak links [7].

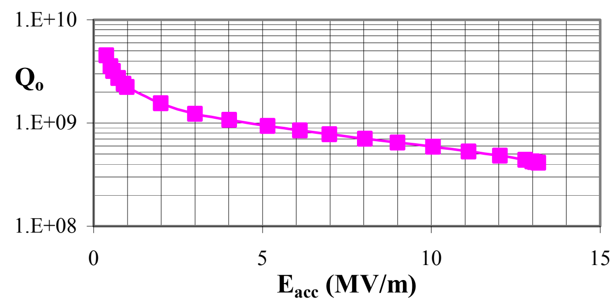

Figure 4: Q_0-E_{acc} curve at 2 K of the Q-degraded cavity EZ02. This cavity was held at 100 K for a total 180 hours. The Q_0 at the lowest measured E_{acc}=0.37 MV/m was 4.54E9, which was still lower than the initial value of ~6E9 of the non-degraded cavity.

Temperature to recover the Q disease

To determine the temperature at which the Q disease recovers, we tried to warm up the degraded cavity EZ02 from 4 K to 150 K and held it at 150 K for 12 hours and took the Q_0-E_{acc} curve after cooling down to 4 K again. The performance recovered to the initial level. Then, we tried to degrade the cavity again and repeated this procedure at 130 K and 140 K. There was no change from the degraded performance. Therefore, it was concluded that the Q disease heals by warming up the cavity to 150 K, but not 140 K or lower for our spoke cavity EZ02. We have not tested this transition temperature with the cavity EZ01. It might be higher since this transition temperature depends on the concentration of untrapped hydrogen [3].

Hydrogen content in the material

A preliminary measurement on the content and the depth profile of hydrogen (H) was performed using ERDA (Elastic Recoil Detection Analysis). The following 3 Nb samples were tested: A) an untreated Nb that was taken from the Nb sheet that was used to fabricate the spoke cavities, B) chemically polished 155 microns from sample A and C) chemically polished 193 microns from sample A. The chemical polishing was done simulating our standard procedure, i.e., buffered chemical polishing (BCP) using a mixture of $HF:HNO_3:H_3PO_4$=1:1:2 by volume and keeping the solution temperature at <15 °C.

Regarding the depth profile, the H is concentrated within 100 nm from the surface, which is consistent with the data in [4]. As to the amount of integrated content of H, there is only relative comparison at the time of writing. The result was that the 155-micron chemically polished sample showed the least and it was 54 % less than the untreated sample. This may confirm the hypothesis that proper BCP can reduce the amount of H content [5]. The 193-micron polished sample showed an increase of H content by 57 % compared to the 155-micron polished sample. This may indicate that the prolonged chemical polishing might increase the H content. It should be noted, however, that this experiment was the very first attempt and the result is preliminary.

DISCUSSIONS

A superconductor having T_c of 2.18 K?

The R_s versus T curve shown above suggests the presence of a superconductor that has a T_c of 2.18 K. Carefully looking at a figure (Fig. 4) in a past paper [6] that shows similar data with a 4 GHz Q-degraded cavity, one can find a similar change of slope at the same temperature, although this was neglected in the paper because there was another kink at 2.8 K in the figure and it seemed more pronounced. We did not find any change of slope at 2.8 K in our cavity. Producing a model that could explain the phenomenon with a thin layer of a weak superconductor having T_c = 2.18 K is under way.

Difference between the two cavities

As shown above, the amount of Q degradation was found to be different between the two spoke cavities tested. This may indicate that the H content of EZ01 is higher than that of EZ02. To the best of our knowledge, the two cavities were fabricated from the Nb sheets taken from the same lot. The possibilities of H uptake are the conditions of, BCP, rinsing after BCP, and during high-pressure rinsing with ultra-pure water. At the time of writing, the thorough analyses of these conditions have not been done yet and it might be difficult due to lack of detailed data.

SUMMARY AND FUTURE PLAN

We have tested two 350-MHz spoke cavities to investigate the occurrence of Q disease. The following summarizes the findings.

- The Q disease does not occur if the cavity was held in the dangerous temperature range within 24 hours, but it occurs for a prolonged holding time.
- Once the Q disease occurs, the additional R_s increases linearly with the total holding time.
- Q-degraded cavities show a change of slope in the R_s at 2.18 K, which suggests the presence of a weak superconductor having a T_c of 2.18 K.
- One of our cavities showed a full recovery from Q disease by warming up the cavity to 150 °C or higher for 12 hours. The transition temperature was determined to be 140 °C <T< 150 °C, but it may be different depending on the H content.
- A preliminary test on the H content has shown that our standard procedure of 150 micron BCP could reduce the H content by ~ 54 %, although further BCP might increase it again.

Although there is no immediate plan, it would be interesting to see the results of similar 350-MHz spoke cavities being developed elsewhere.

ACKNOWLEDGEMENT

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